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# Mathematical modeling of the electromagnetic processes for the analysis of voltage dips in low-voltage networks containing asynchronous motors and passive loads

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## ABSTRACT

The influence of asynchronous motor and passive loads on the voltage dip evolution is analyzed for low-voltage networks. The results show the influence of the load-type on the voltage dip as well as the margins of critical regions (i.e. where the voltage dip is observed) for various methods of computation.

**Key words** – Power quality, voltage dip, mathematical modeling, asynchronous motor, electromagnetic processes.

## 1. INTRODUCTION

The quality of the power supply depends most of all on those factors such as the reliability of the supply and the power quality (in particular the voltage quality). Voltage dips, therefore, become an important criterion in terms of the power supply being qualitative and reliable. Such voltage dips appear, first of all, as the result of significant power or load changes and, in particular, due to short-circuits. The voltage dips may result in the equipment (computers, engines, safety devices, etc.) to operate improperly or malfunction as, for example, severe data losses, misproduction or even full stop of the technology units due to control system errors. Since the number of consumers, sensitive to the power quality, has been increasing gradually over the last years, the problem of voltage dips becomes more and more important.

A voltage dip is a decrease of the mains r.m.s voltage to a level below 90% of the initial voltage that is limited in time. The voltage dip therefore is characterized by two parameters, namely its magnitude  $\Delta U$  and duration  $\Delta t$ .

Simplified approaches, which make use of a steady-state computation of the short-circuit current [1], generally let us only judge about the depth of the voltage dip. The time-history as well as the value of the duration  $\Delta t$  is not able to be determined by means of the steady-state approach. The behavior and evolution depends on various factors, and mainly on the complex transient electromagnetic processes and

mutual influences between the electric power system and the loads supplied.

## 2. ASYNCHRONOUS MOTOR

A lot of factors, e.g. motors and generators with the corresponding control and protection systems, can not entirely (or only limited) be taken into account within a steady state computation approach.

To take into account the influence of the asynchronous motor on the temporal evolution of voltage dips, a series of extensive transient simulations has been performed with MATLAB/Simulink. The MATLAB libraries offer several presets to describe asynchronous machines and motors. The electrical part of the asynchronous motor is modeled through a state equation of 4-th order, and the mechanical part by a 2-nd order system of equations. All rotor parameters and electrical quantities are viewed from the stator. They are identified by primed variables considered in a two-axis coordinate system (so called d,q-coordinates). The subscripts used are defined as follows:

- $d, q$ : d and q axis quantity
  - $R, s$ : Rotor and stator quantity
  - $l, m$ : Leakage and magnetizing inductance
- The electrical part of the model is represented by the following system of differential equations:

$$U_{qs} = R_s i_{qs} + \frac{d}{dt} \varphi_{qs} + \omega \varphi_{ds}$$

$$U_{ds} = R_s i_{ds} + \frac{d}{dt} \varphi_{ds} - \omega \varphi_{qs}$$

$$U'_{qr} = R'_r i'_{qr} + \frac{d}{dt} \varphi'_{qr} + (\omega - \omega_r) \varphi'_{dr}$$

$$U'_{dr} = R'_r i'_{dr} + \frac{d}{dt} \varphi'_{dr} - (\omega - \omega_r) \varphi'_{qr}$$

$$T_e = 1,5p (\varphi_{ds} i'_{qs} - \varphi_{qs} i'_{ds})$$

with

$$\begin{aligned}\varphi_{qs} &= L_s i_{qs} + L_m i'_{qr} \\ \varphi_{ds} &= L_s i_{ds} + L_m i'_{dr} \\ \varphi'_{qr} &= L'_r i'_{qr} + L_m i_{qs} \\ \varphi'_{dr} &= L'_r i'_{dr} + L_m i_{ds} \\ L_s &= L_{ls} + L_m \\ L'_r &= L'_{lr} + L_m\end{aligned}$$

The mechanical part of the model is represented as follows:

$$\begin{aligned}\frac{d}{dt} \omega_{am} &= \frac{1}{2H} (T_e - F\omega_{am} - T_{am}) \\ \frac{d}{dt} \theta_{am} &= \omega_{am}\end{aligned}$$

with

$T_e$  – electromagnetic torque  
 $T_{am}$  – mechanical torque  
 $H$  – combined rotor and load inertia constant  
 $F$  – combined rotor and load viscous friction coefficient  
 $p$  – number of pole pairs.

### 3. MODELING CONDITIONS

The trade-off between active and passive loads and its influence on the voltage dip evolution is studied in a reference low-voltage network, which is shown in Fig. 1. The proposed reference network includes the following elements:

- transformer with nominal power  $S_{tr} = 630$  kVA,  $u_k = 6\%$ ,  $P_k = 6,5$  kW,
- power of the supplying MS system  $S_k = 250$  MVA, with  $U_N = 10$  kV,  $R/X = 0,1$
- low-voltage cable NAYY 4\*150 mm<sup>2</sup>,
- active power load  $P = 500$  kW,  $\cos \varphi = 0,86$ .

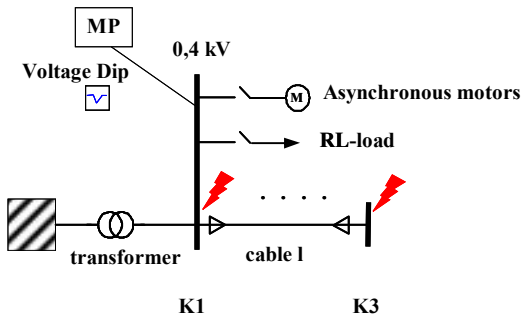


Fig. 1: Reference network where the influence of active and passive loads on the voltage dip is examined

The loads in form of the asynchronous motors (active load) and ohmic-inductive loads (passive load) are plugged in the node-point K1. A permanent 3-phase bolted short-circuit which is not switched-off is assumed in the outgoing cable branch at node-point K3, whereas the resulting voltage dip was monitored in the node point MP. The length of the cable was varied. Thus, different distance conditions between the considered fault and monitoring node points were examined. The asynchronous motor was modeled without the regular rpm control system. Therefore, the transient and steady state approaches can be compared directly. In that scope we note that the latter approach lacks any option of modeling the control system whatsoever.

### 4. RESULTS OF COMPUTATION

First of all, series of simulations were performed with separate contribution from only active loads on the one hand, and only passive loads on the other hand. The steady state and transient computations were performed on the basis of the EN norm of short-circuit current calculation and MATLAB correspondingly. The results of this preliminary step are shown in Fig. 2.

When considering the question of how to detect a voltage dip, the margin corresponding to 0,9U is usually taken. Therefore, one can introduce a critical cable length  $l_{krit}$  as the points of intersection between the curves in Fig 2 and the 0,9U level. Following this way, it is possible to identify the  $l = l_{krit}$  margin for any type of load and/or computational approach. In Fig. 2 an example of the case of a network with asynchronous motors (curve 2s) is shown. The boundary line  $l = l_{krit}$  separates the plot onto 2 regions: at  $l < l_{krit}$  the voltage dip meets the definition criterion and at  $l \geq l_{krit}$  it does not (no voltage dip according to the definition). From this example one can also see that the boundary line is strongly affected by the different types of the load (curves 1s and 2s). In that case, the difference between the 2 approaches is approximately 15% in the cable length at the 0,9U level. This is already a remarkable difference, which can yield a wrong interpretation about the voltage-dip-free region. There is also a considerable difference between transient and steady state computations.

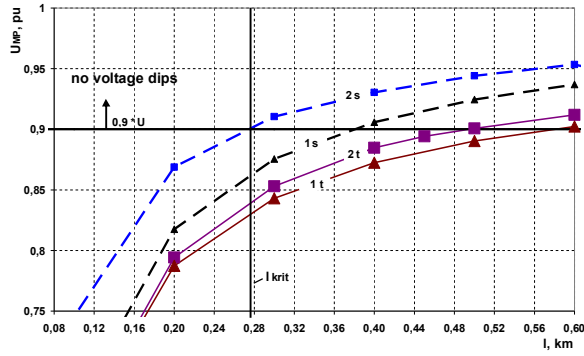


Fig. 2: RMS value of the remaining voltage in MP by three-phase short-circuit in K3 for the network containing passive and active load: ohmic-inductive load with stationary (1s) and transient (1t) calculation approach; active load with stationary (2s) and transient (2t) calculation approach

In the previous analysis the effect of active load or of passive loads on the voltage dip evolution was studied separately. The conclusions on the differences in the results of using the both computation approaches were drawn on the base of the influence of only one type of loads. In practice, however, the most typical scenario of electric power supply is a complex load structure including both active and passive loads at the same time. Therefore, the next step for the study is the joint effect of the motors and ohmic-inductive loads. A series of computations has been performed to study the effect of this complex load. The “active vs. passive” trade-off varied between 2 marginal cases: from only asynchronous motor load to only ohm-inductive one. The sum of the power of the two loads, which contribute to the entire load  $S_{Last}$ , was kept, however, constant. The results based on the simplified EN short-circuit current calculation method are shown in Fig. 3 presenting the remaining voltage level  $U_{MP}$  observed at different points away from the short-circuit position. The marginal lines shown here correspond to the complex load.

In Fig. 4 there are two curves for transient (t) and steady state (s) computations. The latter were again performed following the EN standard. The boundaries are plotted as functions of the parameters cable lengths  $l$  and specific ratio  $S_{AM}/(S_{AM}+S_{RL})$ , which changes from 0 (pure passive load) to 1 (pure active load).

It can be seen from Fig. 4 that both methods lead to different boundary conditions, but show same tendencies for the threshold of the occurrence of voltage dips: by a higher part of motor load ( $S_{AM}/(S_{AM}+S_{RL}) \rightarrow 1$ ) the permissible voltage dip area grows. It depends on the supply of the asynchronous motor. In approaching the case of pure motor load in the network this effect increases.

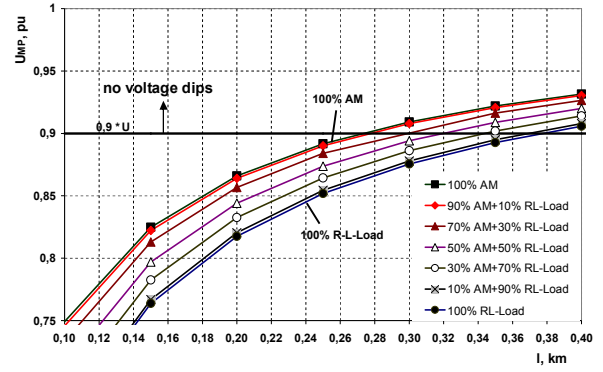


Fig. 3: RMS value of the remaining voltage in MP by three-phase short-circuit in K3 for the network containing mixed load according to stationary calculation approach

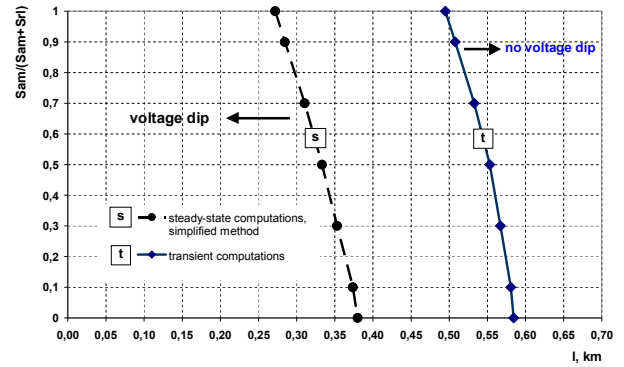


Fig. 4: Margins of the voltage dip region observed at a 3-phase short-circuit (results of steady and transient computations for the network with mixed load)

## 5. SUMMARY

Regarding to the comparison of stationary and transient calculations there is the conclusion that the stationary calculation approach may leads to „wrong“ conclusions of the voltage dip free area. Using the transient calculation approach all networks conditions can be calculated with a high accuracy. It is to recommend the networks containing asynchronous motors (or networks with a high part of motor load) to calculate using convenient software. Further investigations are necessary to generalize the conclusions on the load influences to the power system voltage dips.

## 6. REFERENCES

- [1] IEC 60909-0: Short-circuit currents in three-phase a.c. systems, Part 0: Calculation of currents, 2001 (German version EN 60909-0:2001)